ELECTRICAL SAFETY IN THE HIGH VOLTAGE LABORATORY*

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Abstract

In the process of reevaluating the thoroughness and long-term retention of existing electrical safety training programs at Lawrence Livermore National Lab, a new, intensive training program has been developed. Although it encompasses the electrical safety of utility power it is primarily designed to include the specialized safety issues present in the high energy or pulsed power laboratory. The unique approach is to expose the technical person likely to work in such a hazardous location to a *dynamic, thorough,* and *motivating* presentation designed to leave a long lasting appreciation for the issue of laboratory safety. It is believed that this approach is critical to establish and maintain the sense of long-term safety awareness in an individual that is necessary to assure a continually safe work environment. The newly developed electrical safety awareness course uses a variety of multi-media techniques to accomplish the above goals. This paper will present the design and content of the course as well as the results from the initial presentations.

The Need for Another Electrical Safety Course

Electrical safety in the high voltage or pulsed power laboratory is always given paramount importance in any research endeavor. Yet we may overlook the area of electrical safety as an area for development and improvement, since we often consider it to be a well studied topic. Although excellent safety hardware, procedures, and training programs have been developed many times at many locations accidents still happen. This is in part due to the evolution of new safety needs and considerations as the technologies change, and to the human tendencies to become too comfortably adapted to a routine procedure leading to a loss of critical safety awareness.

Although it may be possible to design a virtually foolproof, automated safety system of interlocks and indicators, the cost and complexity would be prohibitive. In addition, any hardware safety system is subject to failure and also can always be thwarted by human intervention. Thus, the key to any successful implementation of a safety program includes, in addition to the hardware, procedures, and administrative controls, a carefully planned safety training program.

In the process of reevaluating the thoroughness and long-term retention of existing electrical safety training programs at LLNL, a new, intensive training program has been developed. It is primarily designed to include the specialized electrical safety issues present in the high energy or pulsed power laboratory. The unique approach is to expose the technical person likely to work in such a hazardous location with a *dynamic, thorough,* and *motivating* presentation designed to leave a long lasting appreciation for the issue of laboratory electrical safety. It is believed that this approach is critical to establish and maintain the sense of long-term safety awareness in an individual that is necessary to assure a continually safe work environment. The 4 hour multi-media presentation is designed to be *dynamic* in order to capture and maintain the class participant's attention. The course is *thorough* to cover all important and pertinent material, including the more subtle safety problems. And finally, the principle goal is for the presentation to be *motivating* to leave a lasting impression on the class participant.

The course is designed for presentation to any technical personnel working around or with high voltage or high energy electrical systems typical of research laboratories. This includes laboratory scientists and research personnel as well as support staff with mechanical or electrical engineering backgrounds. In addition to the safety issues associated with high voltage and electrical energy storage, the course discusses the secondary hazards that result from the use of high energy electrical systems. These include noise, radiation, explosion, thermal, chemical, and mechanical hazards.

Course Goals

This course was developed to serve as an electrical hazard awareness course. It is designed for various employees trained in electrical, mechanical, and other technical areas. It contains many technical terms and examples, but keeps the theory and design details to a minimum. Thus, as an awareness course, it is useful for everyone exposed to high voltage.

In this course, our objectives for each participant are to:

1. Acquire an acute awareness of all primary and secondary dangers while working with or around high-voltage systems.
2. Identify high-voltage hazards
3. Develop an attitude of safe conduct in hazardous areas
4. Learn the correct usage of equipment and procedures for anticipated interaction with high-voltage hazards

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In the process of reevaluating the thoroughness and long-term retention of existing electrical safety training programs at Lawrence Livermore National Lab, a new, intensive training program has been developed. Although it encompasses the electrical safety of utility power it is primarily designed to include the specialized safety issues present in the high energy or pulsed power laboratory. The unique approach is to expose the technical person likely to work in such a hazardous location to a dynamic, thorough, and motivating presentation designed to leave a long lasting appreciation for the issue of laboratory safety. It is believed that this approach is critical to establish and maintain the sense of long-term safety awareness in an individual that is necessary to assure a continually safe work environment. The newly developed electrical safety awareness course uses a variety of multi-media techniques to accomplish the above goals. This paper will present the design and content of the course as well as the results from the initial presentations.

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5. Learn techniques and attitudes for recognizing and approaching potential unanticipated hazardous situations
6. Learn how to apply engineering and administrative controls in the Laboratory's Electrical Safety Policy

The course is designed to be an awareness course to develop and cultivate a safe attitude and knowledge of electrical safety. The course accomplishes this in a four hour period and although it makes use of many examples of types of hazards and solutions it is not adequate to suffice as a training or qualification course for the actual design and implementation of high voltage electrical systems.

Methods

The newly developed electrical safety awareness course uses a variety of multi-media techniques to accomplish the above goals. Classical lecture is interspersed with demonstrations, accident case history descriptions, slides of laboratory situations, and brief films. In addition to the audio-visual presentation the student receives printed material designed to aid in the retention of the classroom presentation, and to be used later as a reference resource. It includes a complete copy of the viewgraph material presented, a 40 page supportive text to elaborate on many of the key points, and a number of reference appendices. The class enrollment is typically limited to 25 members, allowing questions and discussion. A variety of questionnaires have been given to class participants both before and after the course to gauge the students' prior perception of electrical safety, attitudes towards the safety issues after experiencing the course, retention of key points, and general evaluation of the effectiveness of the course.

The course was also revised for presentation to larger groups (100+) and a video version is being produced. In general prerecorded video presentation is avoided since the subject and goals require active instructor/class participant interaction.

Course Content

The four hour (approximately one half day) course consists of an Introduction, a general statement on Safety Policy at the Laboratory, a discussion of the Physiology of Electrical Shock, a review of the Fundamentals of the Electrical Hazard, and finally presentation of Controlling Electrical Hazards.

Introduction

The introduction serves to impress upon the student the seriousness of the electrical hazard. The probability of electric shock is emphasized due to our constant exposure to its use both in the laboratory and in our everyday lives, the invisible nature of electricity, and the complacency developed due to an individual's possible prior survival of a "mild" electric shock. Then, a number of the applications of high voltage electricity in the laboratory are listed. A presentation of the course objectives serve not only to justify the need for and purpose of the course, but also to outline the next four hours of presentation. A few definitions of key terminology are given.

Although the course was primarily designed in response to the high voltage (in the kilovolt range) hazard in the research laboratory in the introduction the term high voltage is redefined for electrical safety purposes. For the duration of the course and for electrical safety considerations high voltage is defined as any voltage that could result in a serious electrical shock. Thus, high voltage is any voltage above 50 volts ac, dc, or pulsed. It is stressed that the majority of deaths from electric shock occur from exposure to 110 V ac.

Safety Policy

The policy for electrical safety at LLNL is discussed briefly. The responsibility of the individual, the supervisor, and the manager are discussed. Pertinent safety policy documents are listed.

Physiology of Electric Shock

This very important section on the physiology of electric shock serves to create an awareness in the class participant of the seriousness of electric shock. The response of the human body to applied electric current is discussed. This section covers:

What electric shock means
Effects of shock on the human body
Potential injuries caused by electric shock
Factors affecting the severity of shock
What determines the current level in a shock
Rescue and resuscitation from electric shock
Examples of electric shock accidents

This section is very important as most of the attendees are not aware of the sensitivity of the body to electric current and the range of injuries that can result. Ventricular fibrillation, damage to cardio and pulmonary rhythms, and injury from burns and falls are all discussed. Many shock examples ranging from electrocution, permanent injury, to cases of recovery are presented.

This section includes a video on the susceptibility of the heart to electric shock and a taped interview of a witness to a serious shock accident. The physiology section captivates the students attention and serves to reinforce the importance of the subject of electrical safety.

Fundamentals of the Electrical Hazard

This section reviews some electrical principles and terminology in order that different types of electrical hazards and their reduction can be discussed. The following topics are presented:

What is electrical energy ?
What and where is electricity used ?
Materials used in electrical systems
How is electricity transported ?
What is electrical breakdown of an insulator ?
What are some of the types of electrical hazards ?
Potential gradient and grounding
Other hazards associated with electricity
Laboratory examples of electrical hazards.

This section includes an impressive video of electrical energy storage and several useful classroom demonstrations.

An important part of this section is a discussion of energy storage and capacitor safety. Several of the demonstrations focus on the unique hazards presented by energy storage capacitors in the pulsed power laboratory. Secondary hazards that are often found in laboratory electrical systems are discussed. They include fire, explosion, chemical toxicity, noise, intense light, x-rays,

and rf radiation. Examples presented include utility power distribution, high voltage dc, rf sources, pulsed power circuits, and lightning.

Controlling Electrical Hazards

This section introduces the mitigation of the electrical hazard. After a brief discussion of the purpose and need for electrical safety training a detailed description of administrative controls (safety procedures) and engineering controls (design techniques) is given.

It is very important to understand that no level of hardware protection is immune to failure. Thus, it is very important that good safety design be implemented in conjunction with carefully planned safety procedure. In addition to some general rules of safe practice in dealing with electrical systems existing codes and practices are summarized. These include the National Electrical Code, the National Electric Safety Code, federal regulations, the California Administrative Code, municipal codes, the LLNL Health and Safety Manual Chapter 23, and the LLNL Engineering Department Electrical Safety Policy. Administrative controls and procedures discussed include Operating Safety Procedures (OSPs), Facility Safety Procedures (FSPs), and the Lock and Tag Procedure. Generalized approaches to "safeing" a high voltage or energy storage system are presented. Procedures include those for operation, maintenance, and repair. The special hazards present during the measurement and testing of energized high voltage systems are discussed.

Basic safety considerations for design include the concept of fail-safe design and different types of protection strategies. A number of general safety criteria for the design and construction of electrically safe systems are listed. Some safety criteria for the design and construction of specific systems (such as capacitive energy storage systems) are presented.

Finally, this section concludes with a review of some examples of hidden electrical dangers which can cause electric shock accidents. These include disconnected or poor grounds, potential gradients in a ground fault, faulty measuring equipment, improper procedure on the part of others, and poor documentation.

Summary and Conclusion

The course concludes with the following statement:

Safety is important for your health. *Safety* is important for your life! YOU are responsible for your safety.

Always have an awareness for safety, no matter how trivial the task and no matter how experienced you are.

Electrical safety means:

- **don't** work alone,
- **think** before you touch,
- **never assume** it's safe,
- always **follow procedure** and use controls,
- if in doubt **ask**, and
- continually **review** your knowledge and education.

Think safe, be safe.

Course Success

During the first 6 months this course entitled High Voltage Safety Awareness has been presented to approximately 400 engineers and technicians primarily from electrical and mechanical engineering disciplines. The course has received high acclaim. Typically class attendants feel that the course is appropriate for everyone from the beginner, through the novice up to state-of-the-art workers. Most of those surveyed feel that the course was pertinent for use in 75 to 100 % of their job assignment. Over 95 % of those surveyed feel that they had the appropriate background to take this particular course. With few exceptions the course materials are found to be useful for current and future use.

Summary

A new hazard course which treats electrical safety hazards in the high voltage and high energy laboratory has been developed. The course uses a number of methods to motivate and interest the class attendees on the serious subject of electrical safety. The class has been very successful at stimulating engineers and technicians to take a new look at electrical safety.

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